Technology Input to Living With a Star Measurement Requirements

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Outline of Talk

- Introduction
  - Spacecraft, instrument, and technology trends
- Requirement 1: Flight testbeds
- Requirement 2: Environment monitoring
- Requirement 3: Improved prediction models and tools
- Summary

Introduction

- The goal of engineers is to provide the optimum solutions within the constraints or cost, schedule, and performance requirements.
  - *This is in order to provide scientists with the best solution for reliable systems, accurate data, and improved science data collection and analysis.*
- This talk focuses on radiation issues, but other space environments should be considered

Technology – Customer Base

- Uncrewed Flight Projects
  - NASA
    - System/subsytem disciplines
    - Instrument and detector developers
    - Contract primes (Ball, Lockheed Martin, etc.)
- Technology Development
  - NASA Cross-Enterprise, etc.
  - DoD, DOE
- Technology Evaluation
  - HQ/Code AE - NASA Electronic Parts and Packaging (NEPP) Program
  - DoD, DOE - Partnership in radiation effects research programs
    - DTRA, NSWC, NRL, AFRL, etc.

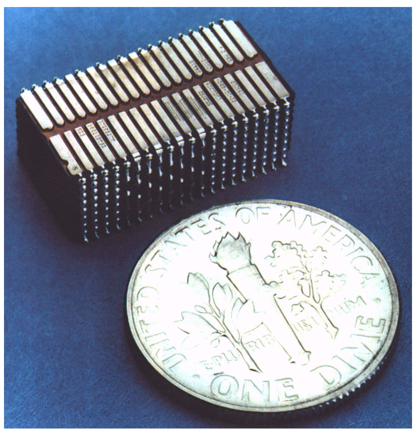
General Trends for Satellite Programs

- Reduce cost
  - in all phases of satellites (design, development, integration, operations, …)
- Reduce mass and volume (1 lb ~ $5K in launch costs)
- Increase performance
  - capabilities such as hyperspectral imaging, increasing data volumes and bandwidth, etc...
- Reduce satellite development time
  - NASA's Near Earth Asteroid Rendezvous (NEAR) reduced development time from 7 years to 26 months
  - improved design tools
- Risk management at the system level
  - Risk avoidance no longer feasible

Faster, better, cheaper (FBC)

Sample Technology Trends

- Increased device/system performance and integration



TRW/Staktek
Commercial Memory Stack
(for use on EO-1)

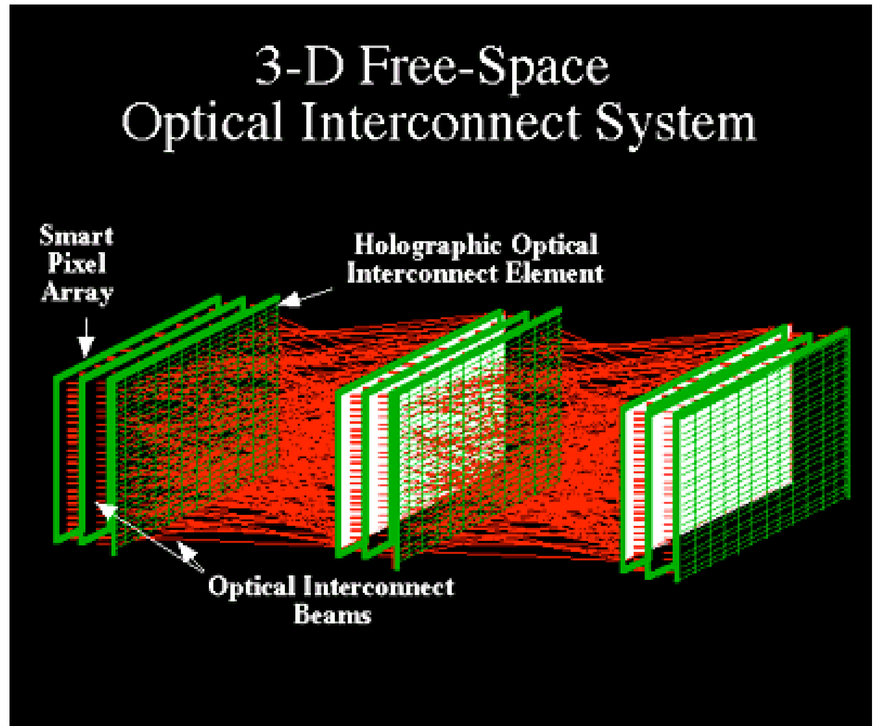


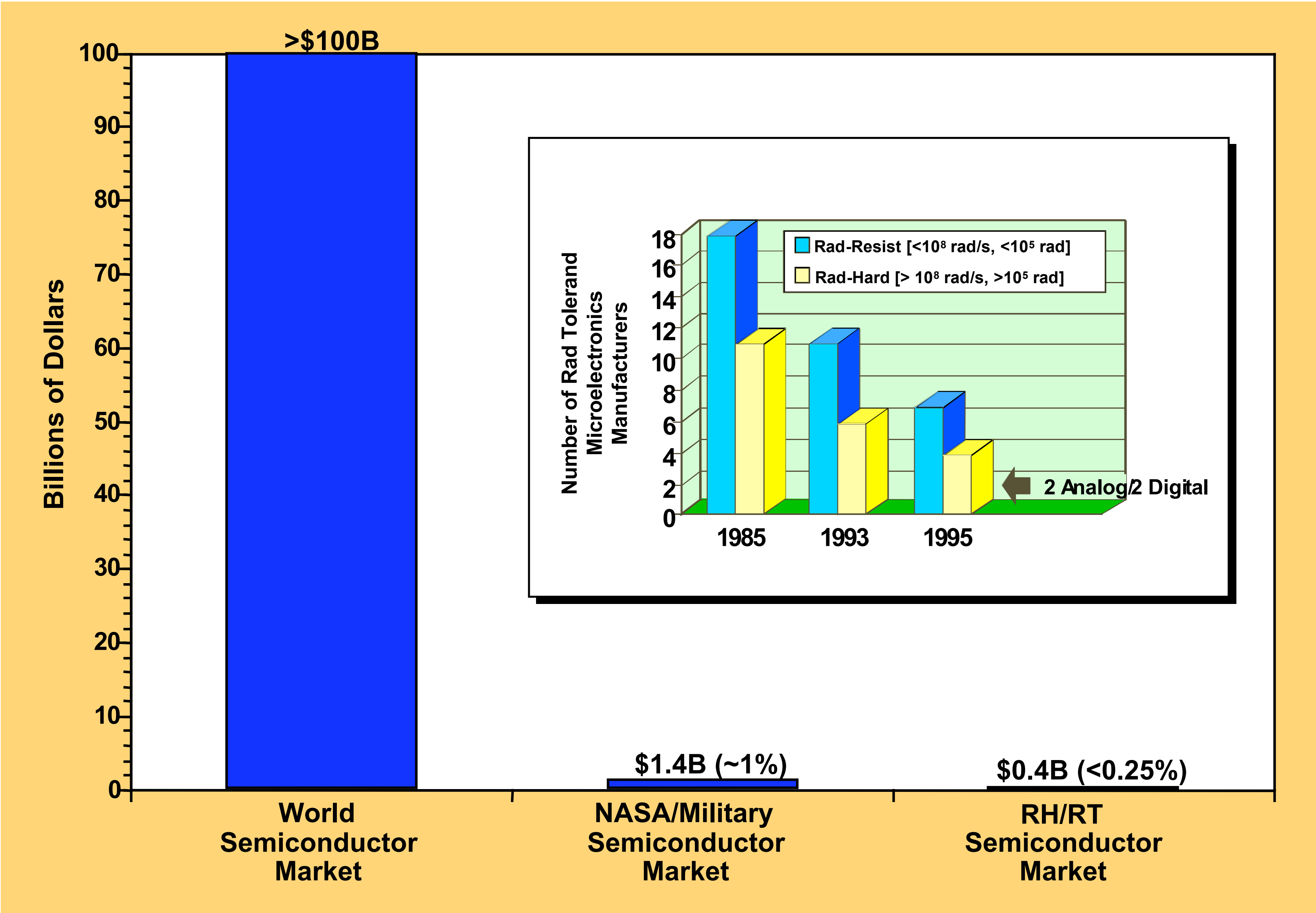
Figure 2.3.2

3-D system based on smart pixel arrays (SPAs) and holographic optical interconnect elements (HOIEs). Each SPA element consists of a VCSEL transmitter, photo-receiver, and a 1-bit microprocessor. The HOIEs enable global connectivity (connection between any transmitter and any receiver on adjacent arrays).

Implication to Design: Three Prime Technical Drivers

- Commercial and emerging technology devices are more susceptible to radiation (and in some cases have new radiation effects) than their predecessors. Trend is accelerating.
- There is much greater uncertainty about radiation hardness because of limited control and frequent process changes associated with commercial processes.
- With a minimization of spacecraft size and the use of composite structures,
  - Amount of effective shielding against the radiation environment has been greatly reduced, increasing the internal environment at the device.
- **THESE THREE DRIVERS IMPLY THAT WE ARE USING MORE RADIATION SENSITIVE DEVICES WITH LESS PROTECTION.**

The Space Semiconductor Market - Reduced Options for Risk Avoidance

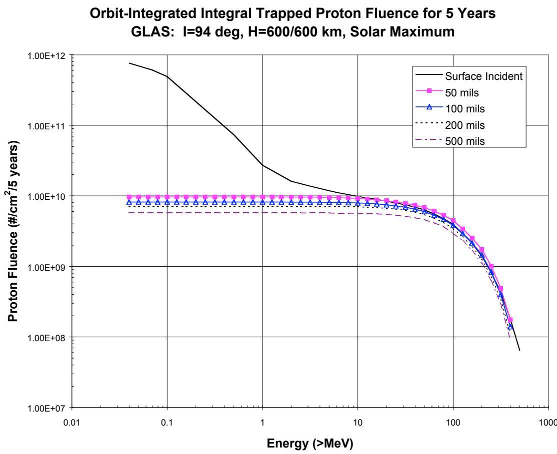


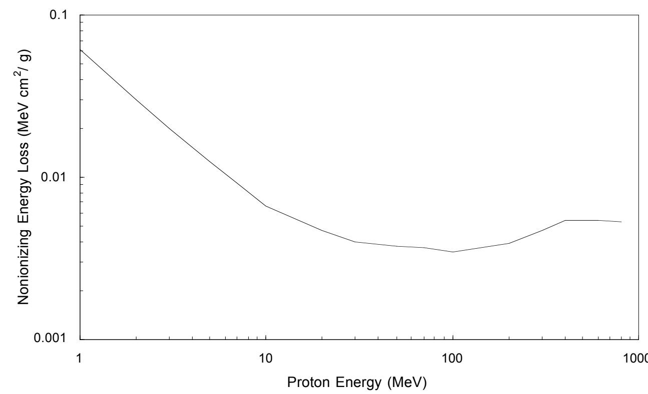
Technology Susceptibility to Radiation - *What energetic particles are of primary concern to these technologies*

- Protons, Electrons, Neutrons
  - Energy ranges of interest are a function of external spectrum transported to sensitive technology
    - Technologies such as solar cells may be exposed to a very wide range of energetic particles (example: protons keV - GeV)
  - Main contributant to long-term effects (Total Ionizing Dose - TID, Displacement Damage)
- Single particle effects (Soft Errors, Hard Errors)
  - Protons, Galactic Cosmic Rays (GCR), Neutrons (secondary)
  - Assuming some effective shielding, higher energy particles (GCR with LETs>1MeV*cm^2/mg or Protons >25 MeV, for example) are prime microelectronics enemy
- Charging
  - Electrons (keV-MeV)

Example: Proton Spectra and Technology

1.

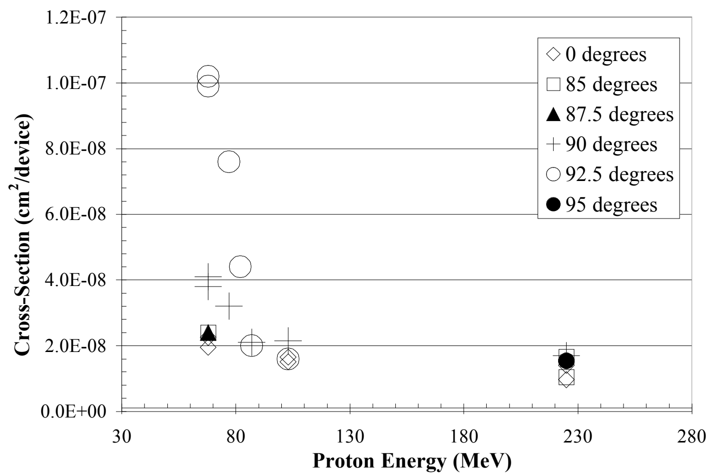




After: G.P. Summers, et al., "Displacement Damage in GaAs Structures," IEEE Trans. Nucl. Sci., Vol. NS-35, No. 6, pp. 1221-1226, Dec. 1988

<u>Effective Damage = Raw Environment Transported to Device then Mapped with Damage Factors</u>

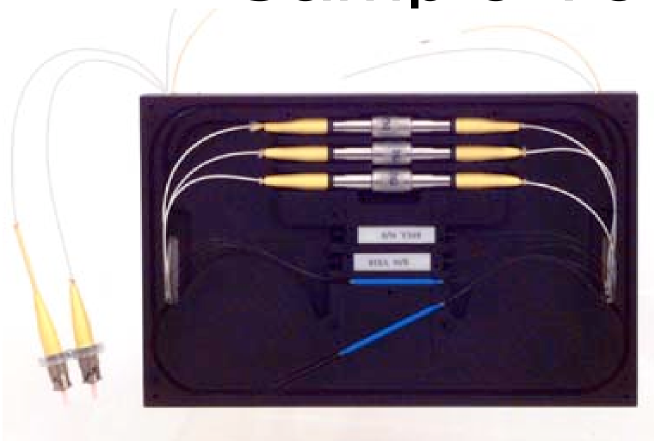
2.



Proton Energy and Angular Dependence of an Optical Detector

- Applies to communication systems, etc.
- New technology model needed to create flight predictions (semiconductor physics)

Sample Technologies and Radiation



Erbium-doped fiber amplifier
http://public1.lucent.com/museum/1986ebf.html

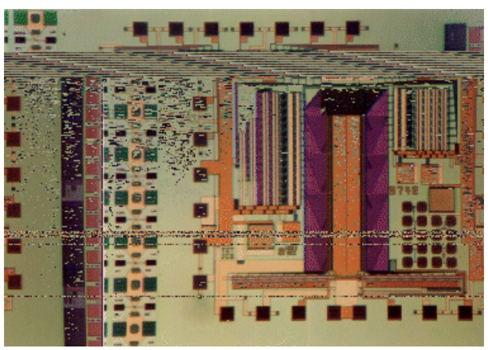
Being considered for space communication systems such as those with phased-array antennas

***Radiation Issues*:**
Preliminary results show "some" TID sensitivity; needs further exploration

Power PC Microprocessor
http://www.chips.ibm.com/products/ppc/

Enable on-board autonomy such as data processing,altitude control, docking, etc.

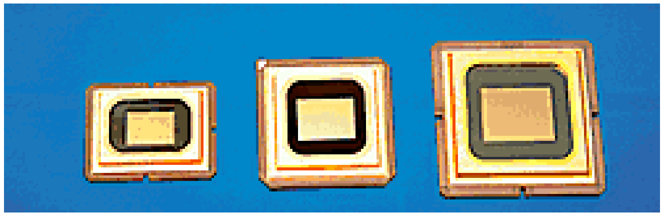
***Radiation Issues*:**
Can be very sensitive = complex system design



SiGe IC

May provide "true" system-on-a-chip (SOC) solution with high performance and low power

***Radiation Issues*:**
Good TID and damage expected;
Preliminary SEE data on cells shows high SEU sensitivity (1st order hardening attempt)



SVGA 848x600; 508, 800 mirrors
XGA 1024x768 chip with black aperture; 786,432 mirrors
SXGA 1280x1024; 1,310,720 mirrors
http://www.ti.com/dlp/docs/business/resources/library/dmmd.shtml

MEMS

Advantages:

Integrates electrical and mechanical worlds
Reduced mass
Increased precision and performance

Applications:

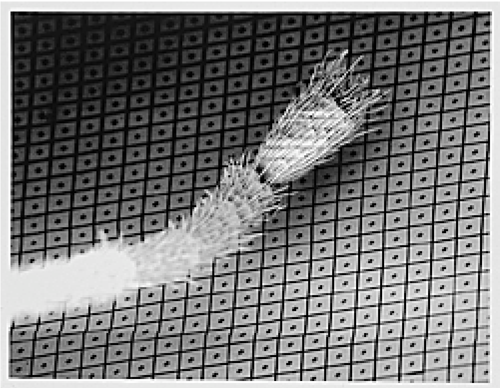
Navigation systems
Improved detector systems
Embedded sensors such as vehicle integrity
Heating and cooling systems
Remote exploration, ...

Radiation Issues:

Limited data: Mixed results

Comment:

Technology is still emerging
>$14B market projected by 2000



Micrographic photo of ant leg on the DMD surface.
Each mirror is 16 μm2 with 1μm separtion between pixels.
http://www.ti.com/dlp/docs/business/
resources/library/pixels_micro.shtml

SXGA 1280x1024; 1,310,720 mirrors
http://www.ti.com/dlp/docs/business/resources/library/dmmd.shtml

Sample: System Issue That Impacts Cost and Size

- Use of ultra low power devices
  - reduces overall power consumption requirement for the satellite
  - smaller solar arrays and batteries would be needed
  - overall spacecraft weight and volume savings
  - lowers the heat load which in turn allows a reduced structural housing
- ***Above factors reduce cost and enable science, but what are the reliability and radiation risks?***

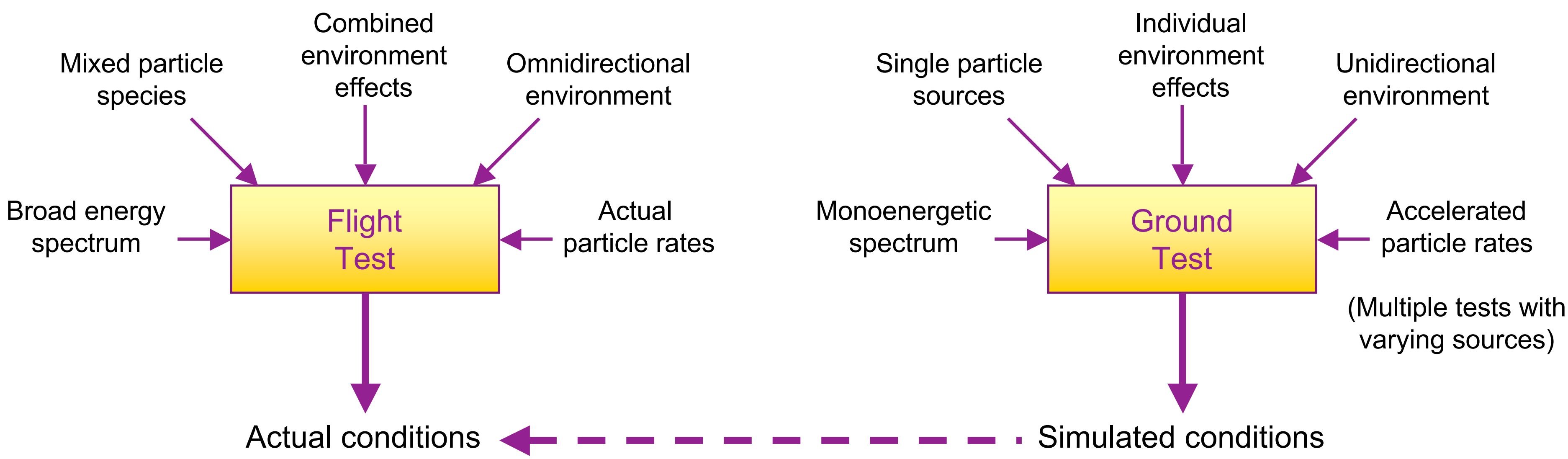
Don’t Let This Be You - Examples of Radiation-Induced Anomalies That Could Affect Science Data Collection

- Hubble Space Telescope(HST): STIS and NiCMOS do NOT operate during passages through the South Atlantic Anomaly (SAA) due to single event transients from high bandwidth optocouplers (change in technology of diode used). Several hits still occur due to galactic cosmic rays.
- Chandra: Excessive particle-damage induced charge transfer efficiency (CTE) degradation on certain CCDs limiting resolution of instrument
- Microelectronics and Photonics Testbed (MPTB) has shown that several “radiation” concerns are real.
  - Enhanced low dose rate effects (ELDRs): some devices fail at lower cumulative TID levels when given actual space dose rates versus accelerated ground tests.
    - Could mean reduced mission lifetime to many missions if ignored
    - Improved test methods and better handle on proper design margins

Requirement 1: Flight Testbeds

- What is a flight testbed?
  - Provides suite of technology and engineering-science experiments
    - Validation/evaluation of new and emerging technologies, tools, methods, and models (technology and environment)
  - Correlation/verification of ground test methods, predictive tools, and environment models to actual flight conditions
    - Allows for improved predictive methods and better test methods: reduced design margins = reduced cost

Requirement: Flight Testbeds - Radiation and Technology

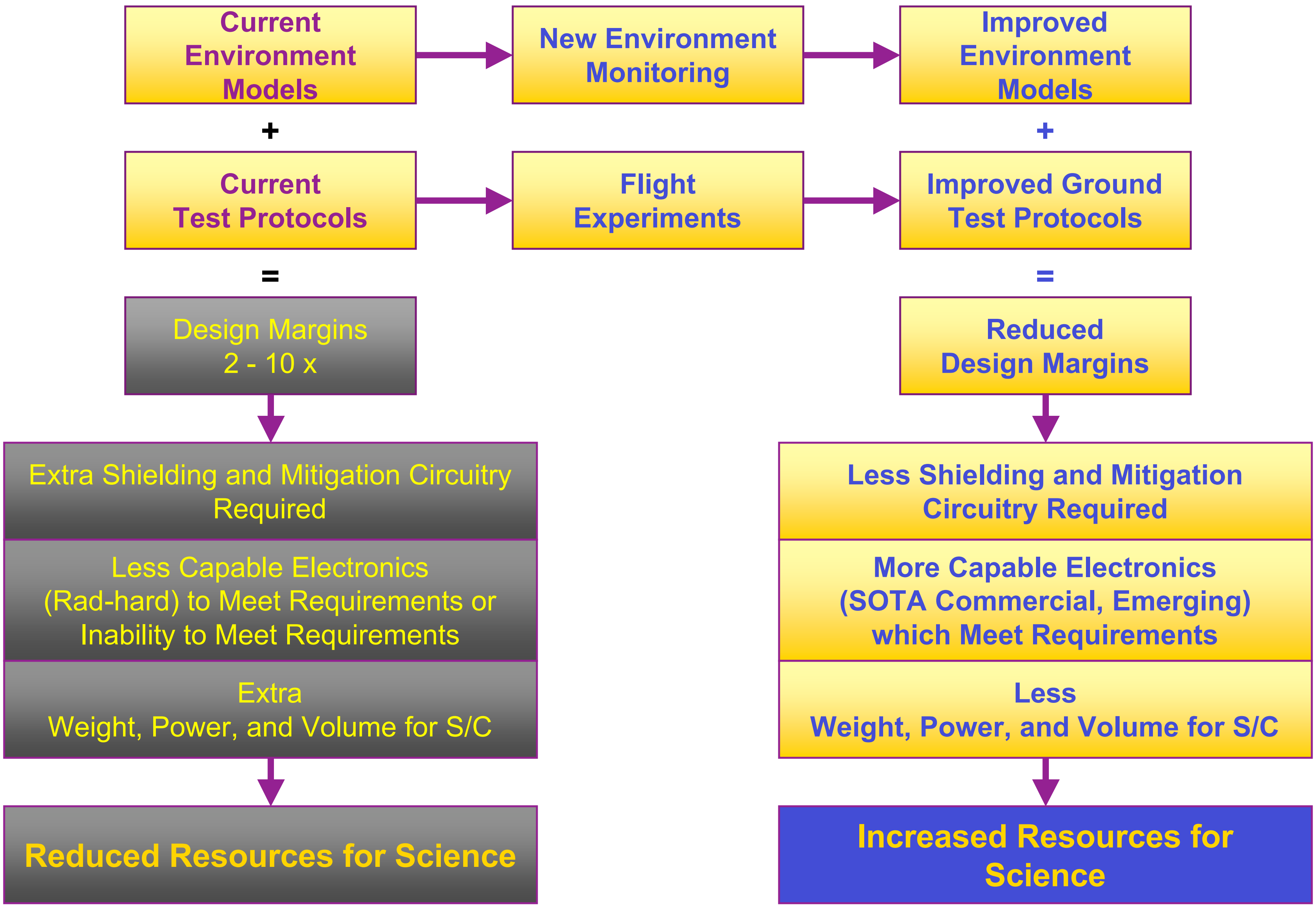


How accurate is the ground test in predicting Space Performance?

Improving Test protocols yields benefits

- **More resources for science**
- **Less conservative testing**
- **FBC Qualification methods**
- **Reduced risk**

The Utility of Flight Testbeds and Environment Monitoring



Flight Experiments - Radiation Perspective

Science — *applied for* → Engineering

Science

Radiation Physics

- High energy particles in space, avionics, and terrestrial
    - Trapped, free-space, solar
- Energetic particles interaction with materials
- Dosimetry (space and ground)
- Mixed particle environments

Semiconductor Physics

- Material properties
- Semiconductor properties
    - Substrate materials
    - Oxides
    - Geometrics
    - Defects, etc.

Engineering

Flight Project

- Requirements
- Hardness assurance
- Testing
- Modeling
- Mitigation/System Performance
- Anomaly resolution

Applied Research

- Advanced Technologies
- Environment models
- Test methods
- Tool development
- Material transport
- Technology/device models and validation
- Facility developments

Requirement 2: Environment Monitoring

- Need to monitor radiation and other environments of interest to technology
  - Dosimeters (TID)
  - Linear energy transfer (LET) spectra monitors (LETs > 0.1 MeV*cm^2/mg needed for SEE)
  - Proton/electron detectors (telescope or other) with high energy monitoring capabilities (damage and SEE)
  - Charging instruments (surface, deep-dielectric, etc.) (charging events)
  - Magnetometers, micrometeroid detectors, etc.
- Allows for
  - Correlation of in-flight technology performance/anomaly to the actual environment
  - Improved environment models (reduced design margins = reduced risk and cost)
- **Required for flight testbeds**
  - *Strongly* recommended for all other missions

Requirement 3: Improved Prediction Models and Tools

- Validation of radiation/reliability models for new and emerging technologies
    - TID, Displacement Damage, SEE, Material Stability, Shielding/Transport Properties, etc. - in a mixed particle environment
- Development of design and predictive tools for new and emerging technologies
- Improved technology-applicable radiation environment models
- All of the above seek to provide improved accuracy for predicting in-flight performance and improved system reliability
    - **Reduced design margins**
        - More technologies able to meet requirements
        - Improved confidence on system performance
        - Reduced cost (less shielding, more “inexpensive” technologies capable of being used

Summary

- New and unproven technologies are rapidly being infused into space systems in order to meet system cost and performance constraints
- This requires
  - Flight testbeds for evaluation and validation
  - Environment monitoring for verification and performance resolution, and
  - Improved technology and technology-applicable environment models to reduce design margins and increase system reliability
- ***The biggest risk for uncrewed missions is technology with unknown space environment performance characteristics***